NON-LWR CONTAINMENT FUNCTIONAL PERFORMANCE REQUIREMENTS

Introduction

The Commission, in its SRM of June 26, 2003, requested the staff to develop performance requirements and criteria for non-LWR containment designs, working closely with industry experts and other stakeholders regarding options in this area, and to take into account such design features as fuel, core, and cooling systems design. The Commission requested that the staff develop functional performance standards for non-LWR containment design and then submit options and recommendations to the Commission.

In response to the SRM, the staff initiated a study of non-LWR containment design information, including an assessment of the safety functions the containment may provide or support, and has taken steps to develop potential options for containment functional performance requirements and criteria.

Background

The functional roles of containment in protecting health and safety can vary significantly among non-LWR designs (e.g., high-temperature gas-cooled, liquid metal, molten salt). Containment functions are derived from the basic reactor-specific safety functions, such as controlling heat generation, removing heat, preventing chemical attack, and containing fission products. Differences in the derived containment functions and performance requirements also reflect differences in the integrated approach that is taken to optimize plant designs to meet a variety of objectives, including NRC regulatory requirements and safety expectations. The specific performance requirements and criteria that have been developed by designers for containment functions are also derived from and integrated with the requirements for other safety-related structures, systems, and components (SSCs) such as fuel, heat removal and coolant purification systems. Containment functional performance requirements and criteria are selected by designers so that the NRC's regulatory requirements (e.g., offsite dose limits) and designer objectives (e.g., meeting NRC safety goals, economics) are met. A non-LWR containment may be defined directly in terms of its derived functions, or indirectly in terms of the SSCs which carry out these functions. These SSCs are located within and compose "containment building system" (or "reactor building system") that resides between the reactor pressure boundary and the environment.

To meet NRC's health and safety acceptance criteria, LWR containment building system designs provide, among other functions, an essentially leak-tight barrier to the release of radioactive materials to the environment independent of the fuel barrier and reactor coolant pressure boundary barrier. This performance requirement reflects LWR technology in that a range of failures of the pressure boundary (i.e., the second barrier to the release of fission products) may cause the fuel (i.e., the first barrier to the release of fission products) to degrade or fail.

For some liquid metal reactor designs, the coolant itself can be highly radioactive and the fuel is not designed to maintain integrity in the absence of coolant. The designers of the liquid metal 4S reactor (i.e., a non-LWR), therefore, also propose a containment building system design that provides an essentially leak tight barrier in the event of an accident that results in the loss of the reactor coolant pressure barrier. However, for advanced HTGRs, the fuel, core, and cooling systems are being designed so that the coolant and internal surfaces within the pressure boundary system contain very limited radioactive material during normal operation and, the fuel remains a highly effective fission product barrier for, anticipated transients and accidents in the absence of coolant. As a result, advanced HTGR designers do not propose to meet health and safety acceptance criteria with a containment building system that provides an essentially leak-tight barrier to the release of radioactivity to the environment. Instead, advanced HTGR designers have proposed a vented low-pressure containment (VLPC) design with a leakage rate that is about two orders of magnitude higher than a conventional LWR containment but reduces radioactive material releases to the environment sufficiently to meet health and safety acceptance criteria (i.e., a “confinement” building). Although venting provides an initial release path to the environment for radioactivity contained within the coolant system, HTGR designers have stated that an unpressurized containment building enhances safety by removing the transport mechanism for fission products that may be released from the core later in a postulated depressurization accident. Advanced HTGR designs, therefore, propose a safety approach that would increase reliance on fuel integrity and the performance of other SSCs to prevent significant fission product release from the fuel, and decrease reliance on SSCs that mitigate significant fission product release. In this regard, preventing significant releases of fission products from the fuel is compatible with the ultimate objective of the Commission’s policy on advanced reactors according to which design approaches are expected to minimize the potential for severe accidents.

Defense-in-depth is fundamental to the NRC’s safety philosophy and is applicable to existing and advanced plants. It ensures that compensatory measures are in place to prevent and mitigate accidents to address uncertainties and also ensures that prevention is appropriately balanced with mitigation. The intent is to ensure that the accomplishment of key safety functions is not dependent on any single element of the plant design. Compared to current LWRs, advanced HTGR designs rely more on design characteristics or features that prevent or delay significant fission product transport from the fuel, core, and reactor pressure boundary (i.e., prevention), and rely much less on design characteristics or features that mitigate or delay radioactive material transport beyond the reactor pressure boundary to the environment (i.e., mitigation). However, for the most limiting accidents, mechanistic fission product transport barriers or delay characteristics and features both within the reactor coolant pressure boundary and beyond the reactor coolant pressure boundary, are generally needed to stay below the Environmental Protection Agency (EPA) guidelines for protective actions at the site boundary. The characteristics or features that significantly delay the transport of fission products may provide additional time for corrective actions to be implemented. For advanced HTGR designs, the long response time characteristic, therefore, may be viewed as an element of defense-in-depth because it provides significant substantial additional opportunity for accident management remedial actions in the course of most accident sequences. The staff is developing a technology-neutral description and process for assessing defense-in-depth for consideration by the Commission as a revision to the Policy Statement on the Use of Probabilistic Risk Assessment Methods in Nuclear Regulatory Activities. This description and process will be key considerations in the staff’s development and evaluation of options for containment functional performance requirements and criteria.

For LWRs, a conventional pressure-retaining, leak-tight containment building system provides significant independent mitigative defense-in-depth, to compensate for uncertainties. These involve uncertainties in initiating events, accident progressions, and accident phenomena which might result in, or increase the severity of, a core damage accident. By utilizing inherent, simple, passive, and reliable means to carry out safety functions, non-LWRs, such as advanced HTGRs, seek to reduce or eliminate many of the kinds of uncertainties that might lead to core damage accidents. Even so, because non-LWRs have not yet accumulated extensive operational and test experience, uncertainties in event probabilities and progressions, passive system performance, and fuel performance are likely to be major contributors to PRA and safety analysis uncertainties. Technology-specific and design-specific research and development, analyses, demonstration plant testing, quality assurance, and other programs are directed, in part, at understanding, quantifying, and reducing such uncertainties. Even so, the staff recognizes that, at the time of any non-LWR licensing review, completeness, modeling, and parameter uncertainties will remain, and will need to be addressed. This could include compensatory measures in the form of additional safety margin, periodic fuel testing to confirm fuel performance, security design or programmatic measures to reduce or minimize insider and outsider initiating event threats, or increased tests and periodic inspections of passive safety systems. Available margins between calculated offsite and onsite releases and release limits may also help compensate for uncertainties. Margins imposed by containment building system performance requirements and criteria for reducing releases to the environment may also be used to compensate for uncertainties. The Commission decision, in the June 26, 2003, SRM on SECY-03-0047, not to modify the emergency planning requirements for non-LWRs at this time may also be viewed as providing additional near-term defense-in-depth to compensate for uncertainties.

The Commission, in its June 26, 1990s SRM (ADAMS Accession No. ML003707885) for SECY-90-016, “Evolutionary Light Water Reactor (LWR) Certification Issues and Their Relationship to Current Regulatory Requirements,” (ADAMS Accession No. ML003707849) stated that advanced reactor containment mitigation functional performance requirements should not be used by the staff to discourage accident prevention in advanced reactor designs. The staff recognizes that non-LWR containment building system functional performance requirements which provide a substantially higher standard than that required to meet the onsite and offsite radiological consequence acceptance criteria could discourage accident prevention. The defense-in-depth description and process being developed for Commission decision will provide a key input to the recommended requirements and criteria for containment functional performance.

Discussion

The staff is currently developing options for non-LWR containment building system functional performance requirements and criteria utilizing applicable Commission technical policies, NRC and industry documents, foreign and domestic technical information, and stakeholder input. The stakeholder input to date includes feedback from industry experts and other stakeholders received at public meetings on November 19, 2003, and January 14, 2004, and from the Nuclear Energy Institute, Westinghouse, and PBMR (Pty) Ltd., in letters dated January 30, February 3, and February 4, 2004, respectively. These stakeholder comments have been considered in the assessment of containment functions, the development of the preliminary options, and the evaluation of the pros and cons for these options. The staff also met with the ACRS on this issue and will consider their comments in further assessing this issue. The staff will also solicit additional stakeholder input on potential options and impacts.

Applicable Commission policy guidance includes the 1986 Policy Statement on Safety Goals for the Operation of Nuclear Power Plants, the 1985 Policy Statement on Severe Reactor Accidents Regarding Future Designs and Existing Plants, the July 30, 1993, SRM (ADAMS Accession No. ML003760774) for SECY-93-0092, "Issues Pertaining to the Advanced Reactor (PRISM, MHTGR, and PIUS) and CANDU 3 Designs and Their Relationship to Current Regulatory Requirements" (ADAMS Accession No. ML040210725), the 1994 Policy Statement on the Regulation of Advanced Nuclear Power Plants, the 1995 Policy Statement on the Use of Probabilistic Risk Assessment Methods in Nuclear Regulatory Activities, the March 11, 1999, White Paper on Risk-informed and Performance-Based Regulation, and the June 26, 2003, SRM for SECY-03-0047, "Policy Issues Related to Licensing Non-Light Water Reactor Designs, and the June 26, 1990, SRM for SECY-90-016.

In SECY-93-0092 the staff addressed the confinement concept for advanced HTGRs by recommending that the acceptability of proposed containment building system designs be evaluated against a functional performance standard rather than a prescriptive criterion. Specifically the staff proposed that containment building system designs must be adequate to ensure that the onsite and offsite radionuclide release limits were met for the event categories within their design envelope. The Commission's July 30, 1993, SRM for SECY-93-0092 approved the staff's recommendation.

NRC and industry documents being considered in the development and assessment of options include NRC regulations for light-water reactors, non-LWR preapplication design and safety analysis reports and related documents and associated staff preliminary safety evaluation reports, and U.S. Department of Energy (DOE) and national laboratory plant design information that had been provided to the NRC for Generation IV non-LWRs. Also being reviewed are selected documents and information pertaining to the containment building system design and safety basis for foreign non-LWRs (e.g., the JAERI High Temperature Engineering Test Reactor and Gas Turbine High Temperature Reactor 300, the Institute of Nuclear Engineering Technology HTR-10, and the Toshiba liquid metal reactor). Based on this review, the staff has concluded that the functional role of non-LWR containment building systems depends on the design and technology and this can include in varying degree:

1. reducing radioactive releases to the environment
2. preventing or limiting potential core damage
3. removing heat to mitigate accident conditions and prevent vital equipment from exceeding design and safety limits
4. protecting vital equipment from internal and external events
5. protecting onsite workers from radiation
6. providing physical protection (i.e., security) for vital equipment

While none of the six functions is exclusively a containment building system function, the first three may be viewed as mitigative functions, while the latter three may be viewed as preventive functions.

To qualitatively evaluate options for containment building system functional performance requirements and criteria, the staff has developed the following preliminary metrics:

Does the option adequately accommodate all containment building system functions (e.g., are there potential adverse effects on plant safety, event consequences, or other containment building system functions)?

Would the option be expected to substantially improve plant safety by

- preventing certain types of accidents?
- significantly reducing fission product release to the environment?
- addressing known uncertainties?

Does the option account for plant risk (e.g., is it risk-informed, does it consider uncertainties)?

Does the option provide flexibility to the designer in meeting the event consequence acceptance criteria (e.g., could it discourage innovation or accident prevention)?

In addition, the staff considered each option from the following perspectives:

Is it technology-neutral and performance-based?

How does it compare to the design approach proposed by existing or prospective non-LWR plant designs?

Does it involve significant incremental costs without commensurate safety benefits?

<u>Future Plans</u>

The staff plans to develop and assess technology-neutral options for non-LWR containment building system functional performance requirements and criteria for reducing radioactive releases to the environment and will continue to assess the feasibility of establishing technology-neutral performance requirements and criteria for the other identified containment building system functions.

Currently, the staff plans to complete activities in this area and provide options and recommendations to the Commission in coordination with the development of a risk-informed technology-neutral framework for future plant licensing described in SECY-03-0059. This will allow the non-LWR containment options to be closely integrated with the defense-in-depth description, probabilistic selection of licensing basis events, scenario-specific source term, deterministic engineering judgement, and the treatment of uncertainties. It will also give the staff an opportunity to obtain further input and feedback from industry experts and other stakeholders in developing the options and recommendations in this area. The staff will also consider Commission policies and regulatory requirements related to physical protection in assessing potential options for non-LWR containment functional performance requirements and criteria. Accordingly, the staff's response to the Commission's questions on Issue 6 will be included in a paper to be provided later this year on framework development.